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CORRELATION OF PHYSICAL FORCES:

BEING THE SUBSTANCE OF A COURSE OF LECTURES DELIVERED IN THE LONDON INSTITUTION, IN THE YEAR 1843.

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PREFACE.

THE subjects of the Course of Lectures embraced by the title of this sketch are much better adapted to oral than to written explanation; they demand at every step experimental illustration, and suggest questions which the Lecturer has an opportunity of answering, but which the writer cannot anticipate.

Notwithstanding the manifold difficulties which surround the task, I am anxious to comply as far as in me lies with the wishes of the Proprietors of The London Institution, and to furnish them with a short resumé of some of those views of Physical Science which I have, in their Theatre, endeavoured to inculcate.

Although these views have not been lost sight of in any of my Courses of Lectures, yet they were more prominently brought forward in the Course delivered in 1843, under the same title as heads this Essay; and it is a short exposition of the principles advanced in this Course, not a report of the Lectures themselves, which I am here attempting to set forth. As far as I am able, I shall give expression in this abstract to such views only as I offered at the time of the Lectures.

In a Lecture which I gave in January, 1842, on the Progress of Physical Science (printed at the request of the Proprietors), I have briefly enunciated the propositions which were explained and illustrated by the Course of 1843, of which Course a tolerably full report appears in the Literary Gazette for January, 1844. As it would interrupt the consecutive developement of my own ideas were I frequently to quote, in the body of this paper, authorities either opposing or coinciding with them, and as I might also be charged with misconstruction of their views, I give, at the conclusion, references to such passages of different authors, published previously to my Lectures, as I have, since their date, found in any way bearing upon the views I have ventured to put forth: most of these were kindly furnished me by Mr. Brayley.

My professional occupations having compelled me to resign an office which I held for five years, I cannot let this opportunity pass without expressing my grateful sense of the uniform kindness I have received from the Proprietors of The London Institution.

4, *Hare Court,*
Temple, August 31, 1846.

CORRELATION OF PHYSICAL FORCES.

When natural phenomena are for the first time observed, a tendency immediately developes itself to refer them to something previously known,—to bring them within the range of acknowledged sequences. The mode of regarding new facts, which is most favourably received by the public, is that which refers them to recognised views,—stamps them into the mould in which the mind has been already shaped. The new fact may be far removed from those to which it is referred, and may belong to a different order of analogies, but this cannot then be known, as its co-ordinates are wanting. It may be questionable whether the mind is not so moulded by past events that it is impossible to advance an entirely new view, but, admitting such possibility, the new view, necessarily founded on insufficient data, is likely to be more incorrect and prejudicial than even a strained attempt to reconcile the new discovery with known facts.

The theory consequent upon new facts, whether it be a co-ordination of them with known ones, or the more difficult and dangerous attempt at remodelling the public ideas, is generally enunciated by the discoverers themselves of the facts, or by those to whose authority the world at that

period defers; others are not bold enough, or if they be so, are not listened to. The earliest theories thus enunciated, obtain the firmest hold upon the public mind, for at such a time there is no power of testing, by a sufficient range of experience, the truth of the theory; it is received solely or mainly upon authority; there being no means of contradiction, it becomes received, in the first instance perhaps, with some degree of doubt, but as the time in which it can fairly be investigated, far exceeds that of any lives then in being, and as neither the individual nor the public mind will long tolerate a state of abeyance, a theory shortly becomes, for want of a better, received as an established truth; it is handed from father to son, and gradually takes its place in education. Succeeding generations whose minds are thus formed to an established view, are much less likely to abandon it. They have adopted it, in the first instance, upon authority, to them unquestionable, and subsequently to yield up their faith would involve a laborious remodelling of ideas, a task which the public as a body will and can rarely undertake, the frequent occurrence of which is indeed inconsistent with the very existence of man in a social state, as it would induce an anarchy of thought—a perpetuity of mental revolutions.

This necessity has its good, but the evil with regard to the point we are considering is, that by this means, theories the most immature frequently become the most permanent, for no theory can be more immature, none is likely to be so incorrect, as that which is formed at the first flush of a new discovery, and though time exalts the authority of those from whom it emanates, time can never give to the illustrious dead such means of analysing and correcting erroneous views as subsequent discoveries confer.

Take for instance the Ptolemaic System, which we may

almost literally explain by the expression of Shakespear, "He that is giddy thinks the world turns round;"—we now see the error of this system, because we have all an immediate opportunity of refuting it, but this identical error was received as a truth for centuries, because, when first promulgated, the means of refuting it were not at hand, and when the means of its refutation became attainable, mankind had been so educated to the supposed truth, that they rejected the proof of its fallacy.

I have premised this for two reasons, first, to obtain a fair hearing by requesting as far as possible that dismissal, from the minds of my readers, of preconceived views, by and in favour of which we are all liable to be prejudiced; and secondly, to defend myself from undervaluing authority, or treating lightly the opinions of those to whom and to whose memory mankind looks with reverence. Properly to value authority, we should estimate it together with its means of information; if a dwarf on the shoulders of a giant can see further than the giant, he is no less a dwarf in comparison with the giant.

The subject on which I am about to treat, viz., the relation of the affections of matter, generally called the Imponderables, to each other and to matter, peculiarly demands an unprejudiced regard. The different ways in which these agencies have been regarded; the different views which have been taken of matter itself; the metaphysical subtleties to which these views unavoidably lead, if pursued beyond fair inductions from existing experience, present difficulties almost insurmountable. Without, however, dilating on these difficulties, I will first shortly sketch what I conceive to have been and to be, in some degree, the notions of the public as to the power and aims of physical science, and then proceed to the examination of the views which

I have had the honor to expose to you in the Course of Lectures alluded to in the Preface.

Not to waste your time with the *à priori* speculations of the early philosophers, who, instead of examining phenomena, and collating instances, until they arrived at general analogies and differences, assumed certain axioms or asserted truisms, and then, by syllogistic deductions, carried them out into complex, and, to us, somewhat unintelligible, conclusions; I will pass to Bacon, the great remodeller of science, who entertained the notion that, by experimentally testing natural phenomena, we should be enabled to trace them to certain primary essences or causes, whence the various phenomena flow. These he speaks of under the scholastic name of forms, a term derived from the Platonic philosophy, but differently applied. He appears to have understood by form—the essence of quality, that in which, abstracting every thing extraneous, a given quality consists, or that which superinduced on any body would give it its peculiar quality; thus the form of transparency is that which constitutes transparency, or that by which, when discovered, transparency could be produced or superinduced. To take a specific example of what I may term the synthetic application of his philosophy. "In gold there meet together yellowness, gravity, malleability, fixedness in the fire, a particular manner of flowing in the fire, a determinate way of solution, which are the simple natures in gold; for he who understands form, and the manner of superinducing this yellowness, gravity, ductility, fixedness, faculty of fusion, solution, etc., with their particular degrees and proportions, will consider how to join them together in some body, so that a transmutation into gold shall follow."

On the other hand, the analytic method, or "the enquiry from what origin gold or any other metal or stone is gene-

rated, from its first fluid matter or rudiments, up to a perfect mineral," is to be perceived by what Bacon calls the latent process, or a search for "what in every generation or transformation of bodies, flies off, what remains behind, what is added, what separated, etc., also, in other alterations and motions, what gives motion, what governs it, and the like." Bacon appears to have thought that qualities separate from the substances themselves were attainable, and if not capable of physical isolation, were at all events capable of physical transference and superinduction.

Subsequently to Bacon a belief has generally existed, and now to a great extent exists, in what are called secondary causes, or consequential steps, by which view one phenomenon is supposed necessarily to hang on another, and that on another, until at last we arrive at an essential cause, subject immediately to the Great First Cause. This notion is generally prevalent both on the Continent and in this country: nothing is more familiar to you than the expression, "study the effects in order to arrive at the causes."

Instead of regarding the proper object of physical science as a search after essential causes, I believe it ought to be, and must be, a search after facts and relations,—that although the word Cause may be used in a secondary and concrete sense, as meaning antecedent forces, yet in an abstract sense it is totally inapplicable; we cannot predicate of any physical agency that it is abstractedly the cause of another, and if, for the sake of convenience, the language of secondary causation be permissible, it should be only with reference to the special phenomena referred to, as it can never be generalised. The misuse, or, rather, varied use, of the term Cause, has been a source of great confusion in physical theories, and philosophers are now by no means agreed as to their conception of causation. The most received view of causation,

that of Brown, refers it to invariable antecedence, *i.e.*, we call that a cause which invariably precedes, that an effect which invariably succeeds. Physically speaking, it is difficult to separate the idea of causation from that of force, and these have been regarded as identical by some philosophers. To take an example which will contrast these two views; if a floodgate be raised, the water flows out; in ordinary parlance, the water is said to flow, *because* the floodgate is raised; the sequence is invariable, no floodgate, properly so called, can be raised without the water flowing out, and yet in another, and perhaps more strict, sense, it is the gravitation of the water which *causes* it to flow. But though we may truly say that, in this instance, gravitation causes the water to flow, we cannot in truth abstract the proposition, and say, generally, that gravitation is the cause of water flowing, as water may flow from other causes,—atmospheric pressure, for instance, which causes water to flow into a vacuum,—and gravitation may, under certain circumstances, arrest, instead of causing, the flow of water.

Upon neither view, then, can we get at anything like abstract causation; if, with Brown, we regard causation as invariable sequence, we can find no case in which a given antecedent is the only antecedent to a given sequent; thus, if water could flow from no other cause than the withdrawal of a floodgate, we might say abstractedly that this was the cause of water flowing; if, again, adopting the view which looks to causation as a force, we could say that water could be caused to flow only by gravitation, we might say abstractedly that gravitation was the cause of water flowing,—but this we cannot say; and if we seek and examine any other example, we shall find that causation is only predicable of it in the particular case, and cannot be supported as an abstract proposition,—yet this is constantly attempted.

Electricity and Magnetism afford us a very instructive example of the belief in secondary causation. Subsequent to the discovery by Oersted of Electro-Magnetism, and prior to that by Faraday of Magneto-Electricity, Electricity and Magnetism were believed by the highest authorities to stand in the relation of cause and effect, *i.e.*, electricity was regarded as the cause, and magnetism as the effect, and where magnets existed without any apparent electrical currents to cause their magnetism, hypothetical currents have been supposed, for the purpose of carrying out the causative view; but magnetism may now be said with equal truth to be the cause of electricity, and electrical currents may be referred to hypothetical magnetic lines; again, if electricity cause magnetism, and magnetism cause electricity, why then electricity causes electricity, which is absurd.

To take another instance, which may render these positions more intelligible. By heating two bars of Bismuth and Antimony in contact, a current of electricity is produced, and if their extremities be united by a fine wire, the wire is heated. Now, here the electricity in the metals is said to be caused by heat, and the heat in the wire to be caused by electricity, and in a concrete sense this is true; but can we thence say abstractedly that heat is the cause of electricity, or that electricity is the cause of heat? Certainly not,—for if either be true, both must be so, and the effect then becomes the cause of the cause, or, in other words, a thing causes itself. If you will put any other proposition on this subject, you will find it involve similar difficulties, until, at length, your minds will become convinced that abstract secondary causation does not exist, and that a search after essential causes is vain.

The position which I seek to establish in this Essay is, that the various imponderable agencies, or the affections

of matter which constitute the main objects of experimental physics, viz., Heat, Light, Electricity, Magnetism, Chemical Affinity, and Motion are all Correlative, or have a reciprocal dependence. That neither, taken abstractedly, can be said to be the essential or proximate cause of the others, but that either may, as a force, produce or be convertible into the other; thus heat may mediately or immediately produce electricity, electricity may produce heat; and so of the rest.

The term Force, although used in very different senses by different authors, in its limited sense may be defined as that which produces or resists Motion. Although strongly inclined to believe that the five other affections of matter, which I have above named, are, and will ultimately be resolved into, modes of motion, it would be going too far, at present, to assume their identity with it; I therefore use the term Force, in reference to them, as meaning that active principle inseparable from matter, which induces its various changes.

Let us begin with Motion—the most obvious, the most distinctly conceived of all the affections of matter. It is a proposition universally received since the time of Newton, that a body in motion will continue so for ever, in the same direction, and with the same velocity, unless impeded by some other body, or affected by some other force than that which originally impelled it; but it is also very generally believed, that if the visible or palpable motion be arrested by impact on another body, the motion ceases, and the force which produced it is annihilated. On the other hand, the view which I venture to submit to you in these lectures is, that force cannot be annihilated, but is merely subdivided or altered in direction or character.

First, as to direction. Wave your hand; the motion

which has apparently ceased is taken up by the air, from the air by the wall of the room, and so, by direct and re-acting waves, continually comminuted, but never destroyed. It is true that, at a certain point, we lose all means of detecting the motion, from its minute subdivision, which defies our most delicate means of appreciation, but we can indefinitely extend our power of detecting it, accordingly as we confine its direction or increase the delicacy of our examination. Thus, if the hand be moved in unconfined air, the motion of the air would not be sensible to a person at a few feet distance, but if a piston of the same extent of surface as the hand be moved with the same rapidity in a tube, the blast of air may be distinctly felt at several yards' distance. There is no greater absolute amount of motion in the air in the second than in the first case, but its direction is restrained, so as to make its means of detection more facile; by carrying on this restraint, as in the air-gun, we get a power of detecting the motion, and of moving other bodies at far greater distances; while the same puff of air which would, in the air-gun, project a bullet a quarter of a mile; if allowed to escape without restraint, as steam does in the candle bomb, would not be perceptible at a yard distance, though the same absolute amount of motion is impressed on the surrounding air.

It may, however, be asked, what becomes of force when motion is arrested or impeded by the counter-motion of another body? This is generally believed to produce rest or entire destruction of motion, and consequent annihilation of force; so indeed it may as regards the motion of the masses, but a new force or new mode of force now ensues, the exponent of which, instead of visible motion, is Heat. I venture to regard the heat which results from friction or percussion, as a continuation of the force which was previously associated with

the moving body, and which when this impinges on another body, ceasing to exist as gross palpable motion, continues to exist as heat. Thus, let two bodies, A and B, be supposed moving in opposite directions (putting for the moment out of the question all resistance, such as that of the air, &c.), if they pass each other without contact, each will move on for ever in its respective direction with the same velocity, but if they touch each other, the velocity of the movement of each is reduced, and each becomes heated; if this contact be slight, or such as to occasion but a slight diminution of their velocity, as when the surfaces of the bodies are oiled, then the heat is slight; but if the contact be such as to occasion a great diminution of motion, as in percussion, or as when the surfaces are roughened, then the heat is great, so that in all cases, the resulting heat is in direct proportion to the diminished velocity. Where instead of resisting and consequently impeding the motion of the body A, the body B gives way, or itself takes up the motion originally communicated to A, then we have less heat in proportion to the motion of the body B, for here the operation of the force continues in the form of palpable motion; thus the heat resulting from friction in the axle of a wheel is lessened by surrounding it by rollers, these take up the primary motion of the axle, and the less, by this means, the initial motion is impeded, the less is the resulting heat. Again, if a body move in a fluid, the heat produced is very trifling, because the particles of the fluid themselves move, and continue the motion originally communicated to the moving body; for every portion of motion communicated to them this loses an equivalent, and where both lose, then an equivalent of heat results.

As the converse of this proposition it should follow, that the more rigid the bodies impinging on each other, the

greater should be the amount of heat developed by friction, and so we find it. Flint, steel, hard stones, glass, and metals, are those bodies which give the greatest amount of heat from friction or percussion, while water, oil, &c., give little or no heat, and from the ready mobility of their particles, lessen its development when interposed between rigid moving bodies. Thus, if we oil the axles of wheels, we have more rapid motion of the bodies themselves, but less heat; if we increase the resistance to motion, as by roughening the points of contact, so that each particle strikes against and impedes the motion of others, then we have diminished motion, but increased heat. I cannot present to my mind any case of heat resulting from friction which is not explicable by this view; friction, according to it, is simply impeded motion, and the resulting heat is a continuation of indestructible force, capable, as we shall presently see, of reproducing palpable motion, or motion of definite masses.

Hitherto I have taken no distinction as to the physical character of the bodies impinging on each other, but Nature gives us a remarkable difference in the character or mode of the force eliminated by friction, accordingly as the bodies which impinge are homogeneous or heterogeneous; if the former, Heat alone is produced; if the latter, Electricity.

We find, indeed, instances given by authors, of electricity resulting from the friction of homogeneous bodies, but, as I stated in these Lectures, I have not found such facts confirmed by my own experiments, and I am happy to see this conclusion corroborated by some experiments of Professor Erman, communicated to the last meeting of the British Association, in which he finds no electricity to result from the friction of perfectly homogeneous substances, as, for instance, the ends of a broken bar. Such experiments as these will, indeed, be seldom free from slight electrical currents,

on account of the practical impossibility of fulfilling the condition of perfect homogeneity in the substances themselves, their size, their temperature, etc., but as the effects produced vary in direction, the resultant effect is nought; indeed it would be difficult to conceive the contrary: how could we possibly image to the mind or describe the direction of a current from the same body to the same body, or give instructions for a repetition of the experiment! It would be unintelligible to say, that in rubbing two pieces of bismuth together, a current of electricity circulated from bismuth to bismuth, or from iron to iron, or from glass to glass, for the question immediately occurs,—from which bismuth to which does it circulate? And should this question be answered, by calling one piece A, the other B, this would only apply to the particular specimens employed, and without heterogeneity, or a distinction in qualities, the phenomenon is absolutely indescribable: we may say that it circulates from rough glass to smooth, from cast iron to wrought, for here there is not homogeneity. It is, indeed, conceivable that when the motion is continuous in a definite direction, electricity may result from the friction of homogeneous bodies; if A and B rub against each other, revolving in opposite directions, parallel currents of positive and negative electricity may be conceived circulating within the metals, and be described by reference to the direction of their motion, but this would be a totally distinct phenomenon from those we are considering, and is, experimentally, unknown.

We may say, then, that in our present state of knowledge, where, and in proportion as, homogeneity exists in the mutually impinging bodies, heat and not electricity is the result of friction and percussion; and, secondly, we may say, that where, and in proportion as, the bodies impinging

are heterogeneous, electricity results; never practically unaccompanied by heat, because perfect heterogeneity is inconceivable, but greater in proportion as the bodies differ, and as the heat is less; thus the friction of similar metals gives little electricity, that of dissimilar metals more, and that of a metal and glass still more, as in the common electrical machine, the action of which is so greatly exalted by the metal mercury.

It is highly probable that heat and electricity are themselves modes of motion; that the gross or palpable motion, which is arrested by the contact of another body, is subdivided into molecular vibrations or undulations, which vibrations are heat or electricity as the case may be. To discuss this theory in full would lead me into a comparative view of the corpuscular and dynamic theories of heat, too long and too foreign to my present object to be detailed here: it will be seen in the course of this essay that I incline to the dynamic theory; my principal aim here, however, is rather to shew the relation of forces, as evinced by acknowledged facts, than to enter upon any explanation of their specific modes of action.

I have said that either of the forces above mentioned may, *mediately* or *immediately*, produce the others, and this is all I can venture to predicate of them, in the present state of science, but I will venture as an opinion, founded after much consideration, that science is rapidly progressing towards the establishment of immediate or direct relations between all these forces. Where, at present, no immediate relation is established between any of them, electricity generally forms the intervening link or middle term.

Motion, then, will directly produce *heat* and *electricity*, and electricity, being produced by it, will produce *magnetism*, a force which is always developed by electrical cur-

rents, at right angles to the direction of those currents. *Light* also is readily produced by motion, either directly, as when accompanying the heat of friction, or mediately, by electricity resulting from motion, as in the electrical spark, which has all the attributes of common light, its sole difference being, as far as I am aware, the position of the fixed lines in its spectrum—a difference which ever obtains with light emanating from different sources, or seen through different media. In the decompositions and compositions which the terminal points proceeding from the conductors of an electrical machine, develope when immersed in different chemical media, we get the production of *chemical affinity* by electricity, of which motion is the initial source. Lastly, motion may be again reproduced by the forces which have emanated from motion; thus, the divergence of the electrometer, the revolution of the electrical wheel, the deflection of the magnetic needle, are palpable movements reproduced by the intermediate modes of force, which have themselves been originated by motion.

If we now take Heat as our starting point, we shall find that the other modes of force may be readily produced by it; to take motion first, this is so generally, I think I may say invariably, the immediate effect of heat, that we may almost resolve heat into motion, and view it mechanically as a repulsive force, a force antagonist to attraction, whether of cohesion or gravitation, and tending to *move* the particles of all bodies, or to separate them from each other: thus, if water be heated, its particles move asunder, forming steam, and this molecular motion will instantly produce the motion of masses, as in the steam engine; whether we raise a piston by weight and pulley, or by heating the air and vapour beneath it, motion becomes the exponent of the amount of heat, as it does of the amount

of gravitation: nor do we by any of our ordinary methods test heat in any other way than by its purely dynamical action—the various modifications of the thermometer and pyrometer are all measurers of heat by motion; in these instruments liquid or solid bodies are expanded and elongated, *i. e.*, moved in a definite direction, and either by their own visible motion, or by the motion of an attached index communicate to our senses the amount of the force by which they are moved.

The phenomena of what is termed latent heat, have been generally considered as strongly in favour of that view which regards heat, either as actual matter, or, at all events, as a substantive entity, and not a motion or affection of ordinary matter.

The hypothesis of latent matter is, I venture with diffidence to think, a dangerous one—it is something like the old principle of Phlogiston, it is not tangible, visible, audible, it is, in fact, a mere subtle mental conception, and ought, I submit, only to be received on the ground of absolute necessity, the more so, as these subtleties are apt to be carried on to other natural phenomena, and so they add to the hypothetical scaffolding which is seldom requisite, and should be sparingly used even in the early stages of discovery. As an instance, I think a striking one, of the injurious effects of this, I will mention the analogous doctrine of "invisible light," and I do this meaning no disrespect to its distinguished author, any more than in discussing the doctrine of latent heat can I be supposed, in the slightest degree, to detract from the merits of the illustrious investigators of the facts which that doctrine seeks to explain.—Is not "invisible light" in fact a contradiction in terms? has not light ever been regarded as that agent which affects our visual organs? invisible light then is darkness, and if it

exist, then is darkness light. I know it may be said, that one eye can detect light where another cannot; that a cat may see where a man cannot; that an insect may see where a cat cannot; but then it is not invisible light to those who see it, the light, or rather the object, seen by the cat may be invisible to the man, but it is visible to the cat, and, therefore, cannot abstractedly be said to be invisible: if we go further, and find an agent which affects certain substances similarly to light, but does not, as far as we are aware, affect the visual organs of any animal, then is it an erroneous nomenclature which calls such an agent, light—a deviation from the plain accepted meaning of words which, when it takes place, is always injurious to that precision of language, which is the safest guard to knowledge, and from the absence of which physical science has materially suffered.

Let us now shortly examine this question, and see whether the phenomena cannot be as well, if not more satisfactorily, explained without the hypothesis of latent matter. Latent heat is supposed to be the matter of heat, associated, in a masked or dormant state, with ordinary matter, not capable of being detected by any test, so long as the matter with which it is associated remains in the same physical state, but communicated to or absorbed from other bodies, when the matter with which it is associated changes its state. To take a common example, a pound or given weight of water at 172°, mixed with an equal weight of water at 32°, will acquire a mean temperature, or 102°; while water at 172°, mixed with an equal weight of ice at 32°, will be reduced to 32°. By the theory of latent heat this phenomenon is thus explained:—in the first case, that of the mixture of water with water, both the bodies being in the same physical state no latent heat is rendered sen-

sible, or sensible heat latent; but in the second, the ice changing its condition from the solid to the liquid state, abstracts from the liquid as much heat as it requires to retain it in the liquid state, which it renders latent, or retains associated with itself, as long as it remains liquid, but of which heat no evidence can be afforded by any thermoscopic test.

I believe this and similar phenomena, where heat is connected with a change of state, may be explained and distinctly comprehended without recourse to the conception of latent heat, though it requires some effort of the mind to divest itself of this idea, and to view the phenomena simply in their dynamical relations. Let us first parallel with purely mechanical actions certain simple effects of heat, where change of state, (I mean such change as from the liquid to the solid, or gaseous to the liquid), is not concerned. Thus, place a bladder within a receiver, and heat the air within to a higher temperature than that without it, the bladder expands, so force the air mechanically into it by the air pump, the bladder expands; cool the air on the outside, or remove its pressure mechanically by an exhausting pump, the bladder also expands; conversely increase the repellent force without, either by heat or mechanical pressure, and the bladder contracts. In the mechanical effects, the force which produced the distension is derived from, and at the expense of, the mechanical power employed, *i. e.*, from the muscular force which works the air-pump, or, it might be, from gravitation, as in a water-wheel, reacting elasticity, as in a coiled spring, or any similar force. In the heating effects the force is derived from the chemical action in the lamp or source of heat employed.

Let us next consider the experiment so arranged that the force which produces expansion in the one case, pro-

duces a correlative contraction in the other; thus, a bladder partly filled with cold air, and contained within another filled with hot air, expands, while the external one contracts, exhibiting a mere transfer of the same amount of repulsive force, the mobility of the particles, or their mutual attraction of cohesion, being the same in each body; in other words, the repulsive force acts in the direction of least resistance until equilibrium is produced, it then becomes a static or balanced, instead of a dynamic or motive force.

Let us now consider the case where a solid is to be changed to a liquid, or, still more, a liquid to a gas; here a much greater amount of heat or repulsive force is required, on account of the cohesion* of the particles to be separated. In order to separate the particles of the solid, precisely as much force must be parted with by the warmer liquid body as keeps an equal quantity of it in its liquid state; it is indeed, only with a more striking line of demarcation, the case of the hot and cold bladder,—a part of the repellent power of the hot particles is transferred to the cold particles, and separates them in their turn, but the antagonist force of cohesion or aggregation necessary to be overcome, being in this case much stronger, requires and exhausts an exactly proportionate amount of repellent force mechanically to overcome it; hence the different effect on a body such as the common thermometer, the expanding liquid of which does not undergo a similar change of state. Thus, in the example above given, in the first mixture, the hot and cold water and the mercury of the thermometer

* The recent experiments of Henry and Donny have shewn that the cohesion of liquids, as far as their antagonism to rupture goes, is much greater than has generally been believed; these experiments, however, make no difference in the view I am putting forth, as, whatever be the character of the attraction, there is a molecular attraction to be overcome, in changing bodies from the solid to the liquid state, which must require and exhaust force.

being all in a liquid state before, and remaining so after contact, the resulting temperature is an exact mean, the hot water contracts to a certain extent, the cold water expands to the same extent, and the thermometer either sinks or rises the same number of degrees, accordingly as it had been previously immersed in the cold or in the hot solution, its mercury gaining or losing an equivalent of repellent force. In the second instance, the substance we use as an indicator does not undergo the same physical change as those whose dynamical relations we are examining. The force, viewing heat simply as mechanical force, which is employed in loosening or tearing asunder the particles of the solid, ice, is abstracted from the liquid water, and from the liquid mercury of the thermometer, and in proportion as this force meets with a greater resistance in separating the particles of a solid than of a liquid, so the bodies which yield the force suffer proportionately a greater contraction.

Another very usual mode of regarding the subject may embarrass you at first sight, but a little consideration will shew you that it is explicable by the same doctrine. You may have experimentally observed, or seen stated in treatises, that water which has ice floating in it will give, when measured by the thermometer, the same temperature as the ice; *i.e.*, both the water and ice contract the mercury of the thermometer to the point conventionally marked as 32°. You may say, how is this reconcileable with the dynamical doctrine, for, according to that, the solid should take from the mercury of the thermometer more repulsive power than the liquid, consequently, the ice should contract the mercury more than the water?

My answer is, that in the proposition as usually stated, the quantities of the water, ice, and mercury, are not taken into consideration, and hence a necessary dynamical element

is neglected: if you take notice of the element of quantity, this objection will not apply. Let the thermometer, for instance, contain $13\frac{1}{2}$ oz. of Mercury, and stand at 100°; if placed in contact with an unlimited quantity of ice at 32°, the mercury will sink to 32°. If the same thermometer be immersed in an unlimited quantity of water at 32°, the mercury sinks also to 32°, not absolutely, perhaps, because, however great the quantity of water or ice, it will be somewhat raised in temperature by the warmer mercury. This elevation of temperature above 32° will be smaller, in proportion as the quantity of water or ice is larger, than the quantity of mercury; and, theoretically speaking, as we know of no intermediate state between ice and water, the contact of a thermometer at a temperature above the freezing point with any quantity of ice exactly at the freezing point would liquefy the whole, provided it had sufficient time; for as every portion of that ice would in time have its temperature raised by the contact of the warmer body, and as any elevation of temperature above the freezing point liquefies ice, every portion should be liquefied. Practically speaking, however, in both cases, that of the water and of the ice, when the quantity is indefinitely great, the thermometer falls to 32°.

Now place the same thermometer at 100°, successively, in one oz. of water at 32°, and in one of ice at 32°; we shall find in the former case it will be lowered only to 54°, in the latter to 32°: apply to this the doctrine of repulsive force, and we get a satisfactory explanation.

In the first case, the quantities both of ice and water being indefinitely great in respect to the mercury, each reduces it to its own temperature, viz., 32°, and the ice cannot reduce the mercury below 32°, because if so, it would receive back repulsive power from the newly formed water, and this would become ice; in the second case, where the

quantities are limited, the mercury does lose more repulsive power by the ice than by the watcr, and the observations I have made in refcrenec to my first illustration, apply.

I do not hcre noticc eertain exceptional eases, as the expansion of water and other liquids at a eertain degree of cold, for these are exceptions upon any view, and explicable by other interfering dynamic causes, sueh, possibly, as crystalline polarization, leaving interstitial spaees.

The general phenomena of heat may, I believe, be all explained upon a purely dynamical view, and without having recourse to the hypothesis of latent matter.

Thus much for the correlation of heat with motion, and if Heat be a force capable of producing *motion*, and motion be capablc of producing the other modes of forcc, it necessarily follows, that heat is eapable, mediately, of producing thcm; we will, therefore, eontent ourselves with inquiring how far heat is capable of immediately producing the other modes of force? It will immediately produce *electricity*, as shewn in the beautiful experiments of Secbeek, one of which I have already cited, which expcriments proved, that when dissimilar metals are made to touch, or are soldered together, and heated at the point of contact, a current of eleetricity flows through the metals, having a definite direction aeeording to the metals employed, which currcnt continues as long as the temperature continues inereasing, or rather, as long as an increasing temperature is gradually pervading the metals, ceases when that temperature is stationary, and flows in thc contrary direction with thc decrement of tcmperature.

To say that heat will produee *light*, is in common parlanec to asscrt a fact familiar to cvery one, but there may bc some rcason to doubt whcthcr the expression to producc light is correct in this particular applieation; the relation

between heat and light is not analogous to the correlation between these and the other four affections of matter. Heat and light appear to be rather modifications of the same force than distinct forces mutually dependent. The modes of action of radiant heat and of light are so similar, both being subject to the same laws of reflection, refraction, double refraction and polarization, that their difference appears to exist more in the manner in which they affect our senses, than in our mental conception of them.

With regard to *chemical affinity* and *magnetism*, perhaps, the only method by which in strictness the force of heat may be said to produce them, is through the medium of electricity, the thermo-electrical current, produced as before described, by heating dissimilar metals, being capable of deflecting the magnet, of magnetising iron, and exhibiting the other magnetic effects, and also of forming and decomposing chemical compounds, and this in proportion to the progression of heat; this has not indeed as yet been proved to bear a measurable quantitative relation to the other forces produced by it, because so little of the heat is utilized or converted into electricity, much being dissipated, without change, in the form of heat.

Heat however directly affects and modifies both the magnet and chemical compounds; the union of certain chemical substances is induced by heat, and cannot take place without it, as for instance, the formation of water by the union of oxygen and hydrogen gases, in other, indeed, in the greater number of cases, this union is facilitated by heat, and in some instances, as in ammonia and its salts, it is weakened or antagonized; in all these cases, however, it must be admitted, that the force of heat seems more a determining than a producing influence, yet to be this, it must have an immediate relation with the force whose reaction

it determines; thus, although gunpowder touched with an ignited wire, subsequently carries on its own combustion or chemical combination, independently of the original source of heat, yet the chemical affinities of the first portion touched, must be exalted by, and at the cost of the heat of the wire, for to disturb even an unstable equilibrium, requires a force in direct relation with those which maintain equilibrium.

Electricity is that affection of matter or mode of force, which most distinctly and beautifully relates other modes of force, and exhibits, to a great extent, in a quantitative form, its own relation with them, and their reciprocal relations with it, and with each other. From the manner in which the peculiar force called Electricity, is apparently transmitted through certain bodies, such as metallic wires, the term *current* is commonly used to denote its progressive direction. It is very difficult to present to the mind any theory which will give a definite conception of its *modus agendi;* the early theories regard its phenomena, as produced either by a single fluid idio-repulsive, but attractive of all matter, or else as produced by two fluids, each idio-repulsive but attractive of the other. No substantive theory has been proposed other than these two, but although this is the case, I think I shall not be unsupported by many who have attentively studied electrical phenomena, in viewing them as resulting not from the action of a fluid or fluids, but as a molecular polarization of ordinary matter, or as matter acting by attraction and repulsion in a definite direction. Thus, the transmission of the Voltaic current in liquids, is viewed by Grotthus as a series of chemical affinities acting in a definite direction; in the electrolysis of water, for instance, a molecule of oxygen is supposed to be displaced by the exalted attraction of the neighbouring elec-

trode, the hydrogen liberated by this displacement, unites with the oxygen of the contiguous molecule of water, this in turn liberates its hydrogen, and so on, the current being nothing else than this molecular transmission of chemical affinity.—Again the electric spark, the brush, and similar phenomena, the old theories regarded as actual emanations of the matter or fluid, Electricity; I venture to regard them as produced by an emission of the material itself, from whence they issue, and a molecular action of the gas or intermedium, through or across which they are transmitted.

The colour of the voltaic arc, or electric spark, is dependent upon the substance of the metal, subject to such modifications of the intermedium; thus, the electric spark or arc from zinc is blue, from silver green, from iron red and scintillating, precisely the colours afforded by these metals in their ordinary combustion; a portion of the metal is also found to be actually transmitted with every electric or voltaic discharge; in the latter case, indeed, where the quantity of matter acted upon is greater than in the former, the metallic particles emitted by the electrodes or terminals can be readily collected, tested, or even weighed; it would thus appear that the electrical discharge arises from an actual repulsion and severance of the electrified matter itself, which flies off at the points of least resistance.

A careful examination of the phenomena attending the electric discharge, or voltaic arc, which is the electric discharge acting on greater portions of matter, tends to modify considerably our previous ideas of the nature of the electric force of ignition, and also of combustion. The voltaic arc is, perhaps, strictly speaking, neither ignition or combustion: it is not ignition, because the matter of the terminals is not merely brought to a state of incandescence, but is physically separated and partially transferred from one electrode to

another, much of it being dissipated in a vaporous state: it is not combustion, for the phenomena will take place independently of atmospheric air, oxygen gas, or any of the bodies usually called supporters of combustion, combustion being, in fact, chemical union, attended with heat and light. In the voltaic arc we may have no chemical union; for if the experiment be performed in a close vessel, in vacuo or nitrogen, the substance forming the electrodes is condensed, and precipitated upon the interior of the vessel, chemically speaking in an unaltered state; thus, to take a very striking example, if the voltaic discharge be taken between zinc terminals in an exhausted receiver, a fine black powder of zinc is deposited on the sides of the receiver; this can be collected, and takes fire readily in the air by being touched with a match, or ignited wire, instantly burning into white oxide of zinc: to an ordinary observer, the zinc would appear to be burned twice; first in the receiver, where the phenomenon presents all the appearance of combustion, and secondly in the real combustion in air. With iron the experiment is more simple, as those who were present at these Lectures may recollect. Iron is volatilised in nitrogen or vacuo, and when a scarcely perceptible film has lined the receiver, this is washed with an acid, which then gives, with ferrocyanide of potassium, the prussian blue precipitate: in this case we readily distil iron, a metal fusible only at a very high temperature.

Another strong evidence that the voltaic discharge consists of the material itself of which the terminals are composed, is the peculiar rotation which is observed in the light when iron is employed, the magnetic character of this metal causing its molecules to rotate by the influence of the voltaic current.

I have entered very fully into this theory in my Lectures on Electricity delivered in the Theatre of this Institution, and it would lead me into too long a digression from the principal subject of this essay, were I further to dilate on it: I will content myself with requesting my readers not to dismiss it as a hastily formed view, without applying it carefully to all the recorded phenomena of electricity; and although, at first sight, some of these may seem inconsistent with it, yet, upon examination, they will, I feel convinced, find these apparent inconsistencies disappear, or at all events they will find the difficulties of other theories more insuperable. Indeed, the hypothesis of matter without weight presents in itself, as I believe, fatal objections to the theories of electrical fluids, which are entirely removed by viewing electricity as force, and not as matter.

To commence, then, with Electricity as an initiating force, we get *motion* directly produced by it in various forms; for instance, in the attraction and repulsion of bodies, evidenced by mobile electrometers, such as that of Cuthbertson, where large masses are acted on; the rotation of the fly wheel, another form of electrical repulsion, and the deflection of the galvanometer needle, are also modes of palpable, visible motion. Electricity directly produces *heat*, as shewn in the ignited wire, the electric spark, and the voltaic arc, in the latter the most intense heat with which we are acquainted, so intense, indeed, that it cannot be measured, every sort of matter being dissipated by it. Electricity directly produces *light* in the same phenomena. It directly produces *magnetism* in all ferruginous bodies placed at right angles to its line of direction, and, indeed, in the substances, of whatever nature, traversed by the electrical current, in a direction at right angles to that of the current; in this case giving us a new character of force, viz., a force acting not in direct

straight lines, but in a tangential or rather rectangular direction. This representation of transverse direction by magnetism and electricity, appears to have led Coleridge to parallel it by the transverse expansion of matter, or length and breadth, though he injured the parallel by adding galvanism as depth; whether a third force exists, which may bear this relation to electricity and magnetism, remains to be proved.

Lastly, electricity directly produces *chemical affinity*, and by its agency we are enabled to obtain effects of analysis or synthesis, with which ordinary chemistry does not furnish us. Of these effects we have examples in the brilliant discoveries by Davy of the alkaline metals, and in the peculiar crystalline compounds made known by Crosse and Becquerel.

Light is, perhaps, that mode of force the reciprocal relations of which with the others has been the least traced out. Until the discoveries of Daguerre and Talbot, very little could be definitely predicated of the action of light in producing other modes of force; and, even, since these discoveries, it is doubted by many competent investigators, whether the phenomena of photography are not mainly dependant upon a separate agent accompanying light, rather than upon light itself. It is, indeed, difficult not to believe that a picture, taken in the focus of the camera obscura, and which represents to the eye all the gradations of light and shade shewn by the original luminous image, is not an effect of light; certain it is, however, that the different coloured rays exercise different actions upon various chemical compounds, and that the effects on many, perhaps on most of them, are not proportionate in intensity to the effects upon the visual organs; those effects, however, appear to be more of degree than of specific difference, and, without pronouncing myself positively upon the question, hitherto so little examined, I think it will be safer to regard the action on

Photographic compounds as resulting from a function of light: so viewing it, we get light as an initiating force, capable of producing, mediately or immediately, the other modes of force. Thus, it immediately produces chemical action, and, having this, we at once acquire a means of producing the others. Those who were present at these Lectures will recollect the experiment in which I shewed the production of all the other modes of force by light:—I may here shortly describe it. A prepared Daguerreotype plate is enclosed in a box filled with water, having a glass front, with a shutter over it; between this glass and the plate, is a gridiron of silver wire; the plate is connected with one extremity of a galvanometer coil, and the gridiron of wire with one extremity of a Breguet's helix; the other extremities of the galvanometer and helix are connected by a wire, and the needles brought to zero. As soon as a beam of either day-light or the oxyhydrogen-light is, by raising the shutter, permitted to impinge upon the plate, the needles are deflected: thus, Light being the initiating force, we get *chemical action* on the plate, *electricity* circulating through the wires, *magnetism* in the coil, *heat* in the helix, and *motion* in the needles.

There are other apparently more direct agencies of light in producing electricity and magnetism, such as those observed by Morichini and others, as well as its effects upon crystallization, but these results have hitherto been of so indefinite a character, that they can only be regarded as presenting fields for experiment, and not as proving the relations of light to the other forces.

Light was regarded by what was termed the corpuscular theory, as being in itself matter or a specific fluid, emanating from luminous bodies, and producing the effects of sensation by impinging on the retina; this theory gave way

to the undulatory one, which is generally adopted in the present day, and which regards light as resulting from the undulation of a specific fluid to which the name of ether has been given, which hypothetic fluid is supposed to pervade the universe, and to permeate the pores of all bodies.

In a Lecture which I delivered in the Theatre of this Institution, in January, 1842, I stated, that it appeared to me more consistent with the facts, to regard light as resulting from a vibration of the molecules of matter itself, and not from a specific ether pervading it; just as sound is propagated by the vibrations of wood, or as waves are by water.*

The transparency or opacity of a body appears to depend entirely upon its molecular arrangement. Thus, if striæ occur in a lens or glass through which objects are viewed the objects are distorted; increase the number of these striæ, and the distortion is so increased that the objects become invisible, and the glass ceases to be transparent, though remaining translucent; but alter completely the molecular structure, as by slow solidification, and it becomes opaque. Take again an example of a liquid and a gas; a solution of soap is transparent, air is transparent, but agitate them together so as to form a froth or lather, and this, though consisting of two transparent bodies, is opaque; and the reflexion of light from the surface of these bodies, when so intermixed, is strikingly different from its reflection before mixture, in the one case, giving to the eye a mere general effect of whiteness, in the other, the images of objects in their proper shapes and colours.

* I am not here speaking of the character of the vibrations of light, sound, or water, which are very different from each other, but am only comparing them so far as they illustrate the propagation of force by motion in the matter itself.

Crystalline bodies again affect light definitely according to their structure. I might weary you with examples, shewing that, in every case which we can trace, the effects of light are changed by any and every change of structure, and that light has a definite connection with the structure of the bodies affected by it. I cannot but think that it is a strong assumption, to regard Ether, a purely hypothetical creation, as changing its elasticity for each change of structure, to regard it as penetrating the pores of bodies of whose porosity we have no proof, and which pores must moreover have a definite and peculiar communication, also assumed for the purpose of the theory. The advocates of the etherial hypothesis certainly have this advantage, that the ether, being hypothetical, can have its characters modified or changed without any possibility of disproof, either of its existence or modifications.

I was not aware at the time that I first adopted the above view and submitted it to you, that the celebrated Leonard Euler had published a somewhat similar theory, and though it has been considered defective by a philosopher of high repute, I cannot see the force of the arguments by which it has been assailed, and therefore for the present, though with diffidence, I still adhere to it; the fact itself of the correlation of the different modes of force is to my mind an irresistible argument in favour of their being produced by a similar agency, and though Electricity, Magnetism and Heat, might be viewed as produced by undulations of the same ether as that by which light is produced, yet this hypothesis offers greater difficulties with regard to the other affections than with regard to light; thus conduction and non-conduction are not explained by it; the transmission of electricity through long wires in preference to the air which surrounds them, and which must be at least equally pervaded

by the ether, is irreconcileable with such an hypothesis. The phenomena exhibited by these forces afford, as I think, equally strong evidence with those of light, of ordinary matter acting from particle to particle, and having no action at a distance; the experiments of Faraday on electrical induction, shewing it to be an action of contiguous particles, are strongly in favour of this view, and many experiments which I have made on the Voltaic arc, some of which I have already mentioned in this essay, are, to my mind, confirmatory of it.

One of the objections to which this view is open, is the necessity involved in it of an universal plenum, for if Light, Heat, Electricity, &c., be affections of ordinary matter, then matter must be supposed to be everywhere where these phenomena are apparent, and consequently there can be no vacuum. The answer appears to me to be, first, that we have no proof of a vacuum ever having been formed; the Torricellian, the most perfect with which we are acquainted, is filled with the vapour of mercury: Davy's experiments on this point prove, at all events, the formation of a vacuum to have been up to his time impracticable. Secondly: the other two theories equally suppose the non-existence of a vacuum; according to the emissive or corpuscular theory, the vacuum is filled by the matter itself, of light, heat, etc.; according to the etherial, it is filled by the all-penetrating ether. Of the existence of matter in the interplanetary spaces, we have some evidence in the diminishing periods of comets, and where from its highly attenuated state, we cannot test the character of the medium by which the forces are conveyed, we may, if we please, call such medium ether.

At the utmost our assumption, on the one hand, is, that wherever light, heat, etc. exist, ordinary matter exists, though it may be so attenuated that we cannot recognise

it by the tests of other forces, such as gravitation. On the other hand, we must assume a specific matter without weight, and of the existence of which we have no evidence but in the phenomena, for the explanation of which we assume its existence. To account for the phenomena, we assume the ether; and to prove the existence of the ether, we cite the phenomena. For these reasons and others above given, I think that the assumption of the universality of ordinary matter is the least gratuitous.

Magnetism, as was proved by the important discovery of Faraday, will produce the other modes of force, but with this peculiarity—that in itself it is static; and, therefore, to produce a dynamic force, motion must be superadded to it; it is, in fact, directive not motive, altering the direction of other forces, but not, in strictness, initiating them. It is, perhaps, more difficult to form a definite conception of the force of magnetism than of any other force. The following illustration may give a rude idea of static polarity. Suppose a number of wind-vanes, say of the shape of arrows, with the spindles on which they revolve arranged in a row, but the vanes pointing in various directions; a wind blowing from the same point with an uniform velocity, will instantly arrange these vanes in a definite direction, the arrow-heads or narrow parts pointing one way, the swallow-tails or broad parts another. If they be delicately suspended on their spindles, a very gentle breeze will so arrange them, and a very gentle breeze will again deflect them, or, if the wind cease, and they have been originally subject to other forces, such as gravity from unequal suspension, they will return to irregular positions, themselves creating a slight breeze by their return. Such a state of things will represent the state of the molecules of soft iron; electricity acting on them, not, indeed, in straight lines, but in a definite direction, produces

a polar arrangement, which they will lose as soon as the dynamic inducing force is removed.

Let us now suppose the vanes, instead of turning easily, to be more stiffly fixed to the axles, so as to be turned with difficulty; it will require a stronger wind to move them and arrange them definitely, but, when so arranged, they will retain their position, and should a gentle breeze spring up in another direction, it will not alter their position, but will itself be definitely deflected; should the conditions of force and stability be intermediate, both the breeze and the vanes will be slightly deflected, or if there be no breeze, and their spindles be all moved in any direction, preserving their linear relation, they will themselves create a breeze. Thus it is with the molecules of hard iron or steel in permanent magnets; they are polarised with greater difficulty, but, when so polarised, they cannot be affected by a feeble current of electricity; again, if the magnets themselves be moved, they themselves originate a current of electricity, and, lastly, the magnetic polarity and the electric current may be both mutually affected, if the conditions of force and stability be intermediate.

The above instance will, of course, be taken only as an approximation, and not as binding me to any closer analogy than is generally expected of a mechanical illustration. In a manner, then, similar to this, magnetism acts on the other dynamic forces, definitely directing them, but not initiating them, except while its polarity is either increasing or decreasing in intensity.

Magnetism, under these conditions, *i.e.*, when conjoined with motion, being capable of producing *electricity*, it follows, from what I have already stated, that it is capable of producing the other modes of force, since electricity is capable of producing them. Thus it can, through the medium of

electricity, produce *heat* and *light*. *Motion* it can directly produce under the above conditions, *i.e.*, a magnet being itself moved or raised, will move other ferruginous bodies; these will acquire a static condition of equilibrium, and be again moved when the magnet is also moved. By motion or arrested motion only, could the phenomena of magnetism ever have become known to us. A magnet, however powerful, might rest for ever unnoticed and unknown, unless it were moved near to iron, or iron moved near to it, so as to come within the sphere of its attraction.

I have no doubt that magnetism will also directly affect the other forces—heat, light,* and chemical affinity—and change their direction or mode of action, and will when in motion directly produce them; but these remain as facts to be elicited by future experimentalists: there are, indeed, experiments of the older philosophers to shew that *chemical affinity* is directly affected by magnetism.†

According to the view I have here ventured to take, magnetism may be produced by the other forces, just as the vanes in the instance given are definitely deflected, but cannot produce them except when in motion; motion therefore is to be regarded in this case as the initiative force, and there can scarcely be said to be a mutual productive power between static magnetism and the other forces.

There is, however, what may be viewed as a dynamic condition of magnetism, *i.e.*, its condition at the commencement and the termination, or during the increment and decrement of its development.

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* In the important discovery of Faraday, published since the delivery of these Lectures, of the deflexion of the plane of the polarised light in solids and liquids when magnetised, there is no reciprocal production of light or magnetism,—the effect is a change of direction; and the same with M. Wartmann's repetition of the experiment, on polarised heat.

† Recently further carried out by Mr. Hunt.

While iron or steel is *being* rendered magnetic, and as it progresses from its non-magnetic to its maximum magnetic state, or recedes from its maximum to zero, it exhibits a dynamic force; the molecules are as far as we can infer, in motion, and while in this state, it will produce the other forces: but it may be said, while magnetism is thus progressive, some other force is acting on it, and therefore it does not initiate; this is true, but the same may be said of all the other forces, they have no commencement that we can trace,—we must ever refer them back to some antecedent force equal in amount to that produced, and therefore the word initiative cannot in strictness apply, but must only be taken as signifying the force selected as the first: this is another reason why the idea of causation is inapplicable to physical production. To this point I shall again advert.

The static condition of magnetism resembles the static condition of other forces,—such as the state of tension existing in the beam and cord of a balance, or in a charged Leyden phial. The old definition of force was, that which caused change in motion, and yet even this definition presents a difficulty; in a case of static equilibrium, such, for instance, as that which obtains in the two arms of a balance, we get the idea of force without any palpable apparent motion; whether there be really an absence of motion may be a doubtful question, as such absence would involve in this case perfect elasticity, and in all other cases, a stability which in a long course of time nature generally negatives, shewing, as I believe, an inseparable connection of motion with matter, and an impossibility of a perfectly immobile or durable state. So with magnetism, I believe no magnet can exist in an absolutely stable state, though the duration of its stability will be proportionate to its original resistance to assuming a polarised condition. This, however, must be taken merely as a matter

of opinion; we have in support of it, the general fact that magnets do deteriorate in the course of years; and we have the further general fact of the instability, or fluxional state, of all nature, when we have fairly an opportunity of investigating it at different and remote periods; in many cases, however, the action is so slow that the changes escape human observation, and until this can be brought to bear over a proportionate period of time, the proposition cannot be said to be experimentally or inductively proved, but must be left to the mental conviction of those who examine it by the light of already acknowledged facts.

Those who can imagine perfectly static forces, regard them as existing in a state of tension, *i.e.*, tendency to motion; so that whenever we get the idea of force, we cannot separate from it the idea of motion or resistance to motion, and when we resolve into a theory the action of the more mysterious forces, such as light, heat, and electricity, we refer them to motion. Whether it be that on account of our familiarity with motion, we refer other affections to it, as to a language which is most easily construed and most capable of explaining them; whether it be that it is in reality the only mode in which all material force is rendered evident; or whether it be that it is the only mode in which our minds, as contradistinguished from our senses, are able to conceive material agencies; certain it is that all hypotheses hitherto framed to account for the varied phenomena of nature, have resolved them into motion: in vain has the mind hitherto sought to comprehend, or the tongue to explain, natural agencies by other means than by motion. Take, for example, the theories of light, to which I have before alluded: one of these supposes light to be a highly rare matter, emitted from, *i.e.*, put in *motion* by, luminous bodies; a second supposes that the matter is not emitted from luminous

bodies, but that it is put into a state of vibration or undulation, *i.e.*, *motion*, by them; and, thirdly, light may be regarded as an undulation or *motion* of ordinary matter, and propagated by undulations of air, glass, etc., as I have before stated. In all these hypotheses, matter and motion are the only conceptions; we in vain struggle to escape from these ideas; if we ever do so, our mental powers must undergo a change, of which, at present, we see no prospect.

Chemical Affinity, or the force by which dissimilar bodies tend to unite, and form compounds, differing, generally, in character from their constituents, is that mode of force, of which the human mind has hitherto formed the least definite idea. The word itself—*affinity*—is ill chosen, its meaning, in this instance, bearing no analogy to its ordinary sense; and the mode of its action is conveyed by an expression of the facts, no dynamic theory of it worthy of attention having been adopted. Its action so modifies and alters the character of matter, that the changes it induces have acquired, not perhaps very logically, a generic contra-distinction from other material changes, and we thus use, as contra-distinguished, the terms physical and chemical. The nearest approach, however, that we can form to a comprehension of chemical action, is by regarding it vaguely as a molecular motion. It will directly produce *motion* of definite masses, by the resultant of the molecular changes it induces: thus, the projectile effects of gunpowder may be cited as familiar instances of motion produced by chemical action. It may be a question, whether, in this case, the force which occasions the motion of the mass, is a conversion of the force of chemical affinity, or whether it is not, rather, a liberation of other forces existing in a state of static equilibrium; but, at all events, through the medium of electricity, chemical affinity may be directly and quantitatively converted into the

other modes of force. By chemical affinity, then, we can directly produce *electricity*: this latter force was, indeed, said by Davy to be chemical affinity acting on masses: it appears, rather, to be chemical affinity acting in a definite direction through a chain of particles; but by no definition can the exact relation of chemical affinity and electricity be expressed, as the latter, however closely related to the former, yet exists where the former does not, as in a metallic wire, which, when electrified or conducting electricity, is, nevertheless, not chemically altered, or, at least, not proved or believed to be chemically altered.

The discovery of Volta—probably the greatest ever made in experimental science—was that which first enabled us definitely to relate the forces of chemistry and electricity. When two dissimilar metals in contact are immersed in a liquid belonging to a certain class, and capable of acting chemically on one of them, what is termed a voltaic circuit* is formed, and that peculiar mode of force called an electric current is generated, which circulates from metal to metal, across the liquid, and through the point of contact.

The quantity of this current, as measured by the quantity of matter it acts upon in its different phenomenal effects, is proportionate to the quantity of chemical action which generated it; and its intensity or power of overcoming resistance, is also proportionate to the intensity of chemical affinity when a single voltaic pair is employed, or to the number of reduplications, when the well-known instrument called the voltaic battery is used.

As Heat, Light, Magnetism, or Motion, can be produced by the requisite application of the electric current, and as

* Perhaps, from the essential dependence of the phenomena on three dissimilar substances in mutual contact, voltaic *trine* would be a more expressive generic term for such combinations, than voltaic circuit.

this is definitely produced by chemical action, we get these forces very definitely, though not immediately, produced by chemical action; let us, however, here inquire, as we have already done with motion and electricity, how far these other modes of force may directly emanate from chemical affinity.

Heat is an immediate product of chemical affinity. I know of no exception to the general proposition, that all bodies in chemically combining produce heat, *i.e.* if solution be not considered as chemical action, and even there, when cold results, it is from a physical change, as from the solid to the liquid state, and not from chemical action.

The definite thermic effects produced by chemical changes, have been lately much studied by Mr. Graham, M. Hess, Dr. Andrews, and Mr. Joule.

The results, excepting those of M. Hess and Dr. Andrews, are complicated, and do not admit of enunciation in such simple propositions, as would be intelligible without much detail. M. Hess and Dr. Andrews have arrived at contrary results, the former concluding, that in chemical combinations, the quantity of heat is determined by the acid, the latter by the basic ingredient.

Light is also directly produced by chemical action, as in the flash of gunpowder, the burning of phosphorus in oxygen gas, and all rapid combustions; indeed, wherever intense heat is developed, light accompanies it; in many cases of slow combustion, such as the phenomena of phosphorescence, the light is apparently much more intense than the heat, the former being obvious, the latter so difficult of detection, that for a long time it was a question, whether any heat was eliminated, and I am not aware that, at the present day, any thermic effects from certain modes of phosphorescence, such as those of phosphorescent wood, putrescent fish, etc., have been detected.

Chemical action produces *magnetism* whenever it is thrown into a linear direction, as in the phenomenon of electrolysis; I may adduce the gas voltaic battery, as presenting a simple instance of the direct production of magnetism by chemical synthesis, oxygen and hydrogen in that combination chemically unite, but instead of combining by intimate molecular admixture, as in the ordinary cases, they act upon water, *i. e.* combined oxygen and hydrogen placed between them, so as to produce a line of chemical action, and a magnet adjacent to this line of action is deflected, and places itself at right angles to the line; what a chain of molecules does here, there can be no doubt all the molecules entering into combination would produce in ordinary chemical actions, but in such cases, the direction of the lines of combination being irregular and confused, there is no general resultant by which the magnet can be affected.

What the exact nature of the transference of chemical power across an electrolyte is, we at present know not, nor can we form any definite idea of it, any more than we know the exact nature of any mode of chemical action; for the present we must leave it as an obscure action of force, of which future researches may simplify our apprehension.

I have now gone through the six affections of matter, for which distinct names have been given in our received nomenclature; that other forces may be discovered, differing as much from these as these differ from each other, is highly probable, and that when discovered, and their modes of action fully traced out, they will be found to be related *inter se* and to these six as these six are to each other, I believe to be as far certain as certainty can be predicted of any future event.

It may in many cases be a difficult question to determine, what constitutes a distinct affection of matter or mode of force. It is highly probable, that different lines of demarcation would have been drawn between the forces already known, had they been discovered in a different manner, or first observed at different points of the chain which connects them. Thus, radiant heat and light are mainly distinguished by the manner in which they affect our senses; were they viewed according to the way in which they affect inorganic matter, very different notions would probably be entertained of their character and relation.

Electricity again was named from the body in which, and magnetism from the district where, it first happened to be observed, and a chain of intermediate phenomena have so connected electricity with galvanism, that they are now regarded as the same force, differing only in the degree of its intensity and quantity, though for a long time they were regarded as distinct.

The phenomenon of attraction and repulsion by amber, which originated the term *electricity*, is as unlike that of the decomposition of water by the voltaic pile, as any two natural phenomena can well be. It is only because the historical sequence of scientific discoveries has associated them by a number of intermediate links, that they are classed under the same category. What is called voltaic electricity might equally, perhaps more appropriately, be called voltaic chemistry. I mention these facts, to shew that the distinction in the name may frequently be much greater than the distinction in the thing which it represents, and *vice versâ;* not as at all objecting to the received nomenclature on these points, nor do I say it would be advisable to depart from it: were we to do so, inevitable confusion would result, and objections equally forcible be found to apply to our new terminology.

Words, when established to a certain point, become a part of the social mind; its powers and very existence depend upon the adoption of conventional symbols; and these suddenly departed from, or varied, according to individual perceptions, the acquisition and transmission of knowledge would cease. Undoubtedly, neology is more permissible in physical science than in any other branch of knowledge, because it is more progressive; new facts or new relations require new names, but even here it should be used with great caution.

> " Si forte necesse est
> " Indiciis monstrare recentibus abdita rerum,
> " Fingere cinctutis non exaudita Cethegis,
> " Continget; dabiturque licentia, sumpta pudenter."

Even should the mind ever be led to dismiss the idea of various forces, and regard them as the exertion of one force, or resolve them definitely into motion, still, we could never avoid the use of different conventional terms, for the different modes of action of this one pervading force.

The term Correlation, which I selected as the title of these Lectures, strictly interpreted, means a necessary mutual or reciprocal dependence of two ideas, inseparable even in mental conception; thus, the idea of height cannot exist without involving the idea of its correlate, depth,—the idea of parent cannot exist without involving the idea of offspring. It has not been much used by writers on physics, but there are a vast variety of physical relations to which, if it does not in its strictest original sense apply, cannot certainly be so well expressed by any other term. There are, for example, many facts, one of which cannot take place without involving the other; one arm of a lever cannot be depressed without the other being elevated,—the finger cannot press the table without the table pressing the finger.

The probability is that, if not all, the greater number of physical phenomena, are, strictly speaking, correlative, and that without a duality of conception, the mind cannot form an idea of them, thus, motion cannot be perceived or probably imagined without parallax or relative change of position. The world was believed fixed, until by comparison with the celestial bodies it was found to change its place with regard to them; had there been no perceptible matter external to the world, we should never have discovered its motion.—In sailing along a river, the stationary vessels and objects on the banks seem to move past the observer; if at last he arrives at the conviction that he is moving, and not these objects, it is by correcting his senses by reflection derived from a more extensive previous use of them; even then he can only form a notion of the motion of the vessel he is in, by its change of position with regard to the objects it passes, that is, provided his body partakes of the motion of the vessel, which it only does when its course is perfectly smooth, otherwise the relative change of position of the different parts of the body and the vessel inform him of its alternating, though not of its progressive movement. So in all physical phenomena, the effects produced by motion are all in proportion to the relative motion; thus, whether the rubber of an electrical machine be stationary, and the cylinder mobile, or the rubber mobile and the cylinder stationary, or both mobile, the electrical effects are, *cæteris paribus*, precisely the same, provided the relative motion is the same, and so, without exception, of all other phenomena. The question of whether there can be absolute motion, or, indeed, any absolute isolated force, is purely the metaphysical question of idealism or realism—a question for our purpose of little import; sufficient for the purely physical enquirer, the maxim "*de non apparentibus et non existentibus eadem est ratio.*"

The sense I have attached to the word correlation, in treating of physical phenomena, will, I think, be evident, from the previous parts of this essay, to be that of a reciprocal production or convertibility; in other words, that any force capable of producing or being convertible into another may, in its turn, be produced by it,—nay, more, can be itself resisted by the force it produces, in proportion to the energy of such production, as action is ever accompanied and resisted by reaction; thus, the action of an electro-magnetic machine is reacted upon by the magneto-electricity developed by its action.

The evolution of one force or mode of force into another, has induced many to regard all the different natural agencies as reducible to unity, and as resulting from one force which is the efficient cause of all the others: thus, one party writes to prove that electricity is the cause of every change in matter; another that chemical action is the cause of every thing; another that heat is the universal cause,—and so on. If, as I have submitted to you, the true expression of the fact is, that each mode of force is capable of producing the other, then any view which regards either of them as abstractedly the efficient cause of all the rest is erroneous; the view has, I believe, arisen from a confusion between the abstract or generalised meaning of the term cause, and its concrete or special sense,—the word itself being indiscriminately used in both these senses.

Another confusion of terms has arisen, and has, indeed, much embarrassed me in enunciating the propositions sought to be proved in these pages, on account of the imperfection of scientific language; an imperfection in great measure unavoidable, it is true, but not the less embarrassing.

Thus, the words light, heat, electricity, and magnetism, are constantly used in two senses, viz., that of the force producing, or the subjective idea of force or power, and of the

effect produced, or the objective phenomenon. The word motion, indeed, is only applied to the effect, and not to the force,—and chemical affinity is generally applied to the force, and not to the effect; but the other four terms are applied indiscriminately to both, for want of a distinct terminology.

I may possibly have occasionally used the same word, at one time in a subjective, at another in an objective, sense; all I can say is, that I cannot avoid this without a neology, which I have not the presumption to introduce, or the authority to enforce. The word force itself, and the idea it aims at expressing, may be objected to by the purely physical philosopher, as representing a subtle mental conception, and not a sensuous perception, or phenomenon; to avoid its use however, if open to no other objection, would be so far a departure from recognised views, as to render language scarcely intelligible. Again, the use of the term forces in the plural might be objected to, by those who do not attach to the term force the notion of a specific agency, but of one universal power associated with matter, of which its various phenomena are but diversely modified effects.

Whether the imponderable agencies viewed as force, and not as matter, ought to be regarded as distinct forces or distinct modes of force, I do not think very material, for as far as I am aware, the same result would follow either view, and I have used the terms indiscriminately, as either happened to be the more expressive for the occasion.

The great problem which remains to be solved, in regard to the correlation of physical forces, is the establishment of their equivalent of power, or their measurable relation to a given standard. Viewed in their static relations, or in the conditions requisite for producing equilibrium or quantitative equality of force, a remarkable relation between chemical affinity and heat, is that discovered in many simple bodies

by Dulong and Petit, and extended to compounds by Neumann and Avogadro: their researches have shewn that the specific heats of certain substances, when multiplied by their chemical equivalents, give a constant quantity as product, or in other words, that the combining weights of such substances are those weights, which require equal accessions or abstractions of heat, equally to raise or lower their temperature. To put the proposition more in accordance with the view we have taken of the nature of heat: each body has a power of communicating or receiving molecular repulsive power, exactly equal, weight for weight, to its chemical or combining power; for instance, the equivalent of lead is 104, of zinc 32, or in round numbers as 3 to 1, these numbers are therefore inversely the exponents of their chemical power, three times as much lead as zinc being required to saturate the same quantity of an acid or substance combining with it; but their power of communicating or abstracting heat or repulsive power is precisely the same, for three times as much lead as zinc is required to produce the same amount of expansion or contraction in a given quantity of a third substance, say water.

Again, a great number of bodies chemically combine in equal volumes, *i.e.*, in the ratios of their specific gravities, but the specific gravities represent the attractive powers of the substance, or are the numerical exponents of the forces tending to produce motion in masses of matter towards each other, while the chemical equivalents are the exponents of the affinities or tendencies of the molecules of dissimilar substances to combine, and saturate each other, consequently, here we have an inverse relation between these two modes of force, gravitation, and affinity.

Were the above relations extended into an universal law, we should have the same numerical expression for the

three forces of heat, gravity, and affinity, and as electricity and magnetism are quantitatively related to them, we should have a similar expression for these forces; but, at present, the bodies in which this parity of force has been discovered, though in themselves numerous, are small compared with the exceptions, and, therefore, this point can only be indicated as promising a generalization, should subsequent researches alter our knowledge as to the elements and equivalents of matter.

With regard to what may be called dynamic equivalents, *i. e.*, the definite relation to time, of the action of these varied forces upon equivalents of matter, the difficulty of establishing them is still greater. If the proposition, which I stated at the commencement of this paper be correct, that motion may be subdivided or changed in character, so as to become heat, electricity, etc., it ought to follow, that when we collect the dissipated and changed forces, and reconvert them, the initial motion, affecting the same amount of matter with the same velocity, should be reproduced, and so of the changes in matter produced by the other forces; but the difficulties of proving the truth of this by experiment, will, in many cases, be all but insuperable; we cannot imprison motion as we can matter, though we may to some extent restrain its direction. Electricity promises us the best means of effecting this, but little has hitherto been done in carrying it out.

In investigating the relations of the different forces, I have in turn taken each one as the initial force or starting point, and endeavoured to shew how the force, thus arbitrarily selected, could mediately or immediately produce or be converted into the others; but it will be obvious to those who have attentively considered the subject, and brought their minds into a general accordance with the views I have

submitted to them, that no forec can, strictly spcaking, be initial, as thcrc must bc somc anterior force which pro-duccd it; we cannot create forcc or motion any morc than wc can create mattcr. Thus, to take an example prcviously noticed, and recede backwards; the spark of light is produced by elcctricity, eleetricity by motion, and motion is produecd by something elsc, say a steam cngine—that is by hcat; this heat is produced by chcmical affinity, *i. e.*, the affinity of the carbon of the coal for the oxygen of thc air; this carbon and this oxygen have becn prcviously climinated by actions difficult to trace, but of thc prc-cxistencc of which we cannot doubt, and in which actions wc should find thc conjoint and alternating effccts of hcat, light, chemieal affi-nity, cte.; thus traeing any force backwards to its ante-cedcnts, we are mcrged in an infinity of changing forms of force; at some point wc losc it, not bccause it has been in fact created at any definite point, but because it resolves itself into so many eontributing forccs, that the evidence of it is lost to our scnscs or powcrs of detection, just as in following it forward into the cffect it produces, it beeomes, as I havc bcfore stated, so subdivided and dissipated, as to be equally lost to our means of detection.

Can we, indecd, suggest a proposition, definitely con-ceivablc by thc mind, of motion without antccedent motion? *I* cannot, without ealling for thc intcrposition of crcativc power, any more than I ean coneeive the suddcn appearance of a mass of mattcr eome from no wherc, and formcd from nothing. With matter, thc impossibility of ereation, humanly speaking, has long been admittcd, though, perhaps, its dis-tinct reception in philosophy may be set down to thc over-throw of thc doctrinc of Phlogiston, and thc reformation of ehemistry, at thc time of Lavoisicr. The rcasons for the admission of the non-annihilation of forcc, appear to bc

equally strong. With regard to matter, there are many cases in which we never practically prove its cessation of existence, yet we do not the less believe in it: who, for instance, can trace, so as to re-weigh, the particles of iron worn off the wheel of a carriage?—who can re-combine the particles of wax dissipated and chemically changed in the burning of a candle? By placing matter, undergoing physical or chemical changes, under special limiting circumstances, we may, indeed, acquire evidence of its continued existence,—weight for weight,—and so we may, in some instances of force, as in definite electrolysis; indeed, the evidence we acquire of the continued existence of matter, is by the continued exertion of the force it exercises, as, when we weigh it, our evidence is the force of attraction; so, again, our evidence of force is the matter it acts upon. Thus, matter and force are correlates, in the strictest sense of the word; the conception of the existence of the one, involves the conception of the existence of the other; the quantity of matter again and the degree of force involve conceptions of space and time. But here I must conclude:—were I to pursue this further, I should be tempted into the alluring paths of metaphysical speculation.

I believe that the same principles and mode of reasoning as I have adopted in this essay, might be applied to the organic, as well as the inorganic, world; and that muscular force, animal and vegetable heat, etc., might, and at some time will, be shewn to have similar definite correlations; but I have purposely avoided this subject, as pertaining to a department of science to which I have not devoted my attention.

My aim has been to give you a generalised view of what I conceive to be the connected results already produced in inorganic physical science, and, thence, to enable you to form

some deduction as to the probable character of the results to be anticipated. It is a great assistance in such investigations to be intimately convinced that no physical phenomenon can stand alone; each is inevitably connected with anterior changes and as inevitably productive of consequential changes, each with the other, and all with time and space; and, either in tracing back these antecedents, or following up their consequents, many new phenomena will be discovered, and many existing phenomena, hitherto believed distinct, will be connected and explained; explanation is, indeed, only relation to something more familiar, not more known, *i.e.*, known as to causative or creative agencies: in all phenomena, the more closely they are investigated, the more are we convinced that, humanly speaking, neither matter nor force can be created, and that an essential cause is unattainable.—Causation, is the will, Creation, the act, of God.

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In the original Lectures I alluded very cursorily to gravitation and Inertia, I have therefore abstained from noticing these forces in the text—Inertia appears to me to be a static condition of the force of gravitation, or in other words resistance to motion occasioned by the force of gravitation—without gravitation I cannot conceive Inertia. Whether this be so or not, as the phenomenal effects of gravitation and Inertia, are, motion and resistance to motion, I have, in considering motion, necessarily included their relations to the other forces. For the identity of gravitation with other modes of attractive force, see Mosotti. *Scientific Memoirs*, 1837, Vol. 1, Page 448. See also Franklin on Inertia. *Miscellaneous Pieces*, 1779, Page 479.

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